SMOKING DEVICE AND METHOD FOR AEROSOL-GENERATION

The invention relates to smoking devices, methods and smoking systems for aerosol generation of a liquid aerosol-forming substrate, and cartridges for such smoking devices. The smoking device and aerosol-generating system are electrically operated devices and systems.

In electrically operated smoking systems for example liquid aerosol-forming substrate is atomized to form an aerosol. Typically, in atomizers a coil of heat wire is wound around an elongate wick soaked in liquid aerosol-forming substrate. Other types of atomizer use ultrasonic vibrations, rather than heat, to atomise a liquid substrate. Therein, vibrations are used to push or draw a liquid through a mesh and atomise the liquid. A problem with most atomizers using ultrasonic vibration is that they are not able to atomize highly viscous liquids as are typically used in electrically operated smoking systems. In addition, many atomizers require high power to achieve a desired atomization rate.

There is need for a smoking device for aerosol-generation of a liquid aerosol-forming substrate that ameliorates these problems. There is need for a smoking device for aerosol-generation of liquid aerosol-substrates requiring small power to achieve efficient atomization.

According to a first aspect of the invention, there is provided a smoking device for aerosol-generation of a liquid aerosol-forming substrate as set out in claim 1. The smoking device comprises a device housing comprising a liquid storage portion comprising a housing for holding liquid aerosol-forming substrate. The device housing may, for example, comprise a cavity for receiving a cartridge therein, the cartridge comprising a liquid aerosol-forming substrate. The smoking device further comprises a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer for generating surface acoustic waves to propagate along a surface of the SAW-atomizer including the atomization region, and at least one output transducer for converting surface acoustic waves into an electrical signal representative of physical information of the atomization region. A supply element is arranged to supply liquid aerosol-forming substrate from the liquid storage portion to the atomization region on the SAW-atomizer. The supply element may fluidly connect the liquid storage portion, for example a cartridge, and the SAW-atomizer, in particular the atomization region on the SAW-atomizer. A control system is configured to operate the SAW-atomizer according to the electrical signal for atomizing the liquid aerosol-forming substrate in the atomization region to generate an aerosol. The control system may, for example, comprise a power source and control electronics connected to the SAW-atomizer. The control system is, for example, adapted to provide an RF-signal to the at least one transducer. The generated aerosol may then be transported in the device housing to a downstream end of the smoking device to a user of the smoking device.

In use, a user may operate the device by operating a switch or by drawing on a mouthpiece of the device. Power may be provided to the SAW-atomizer activating the at least

one input transducer to produce surface acoustic waves (Rayleigh-waves) to propagate along the surface of the SAW-atomizer. The energy of these surface acoustic waves is transferred into the liquid aerosol-forming substrate supplied to the atomization region. The energy supplied into the liquid causes formation of aerosol droplets of the liquid aerosol-forming substrate thus atomising the liquid aerosol-forming substrate from the atomization region. The surface acoustic waves transferred into the liquid basically destabilize the liquid droplet on the surface of the SAW-atomizer such that the surface of the droplet breaks up and forms a mist of aerosol droplets.

This way of generating aerosol has proven to provide reliable and consistent amounts of aerosol from a liquid aerosol-forming substrate for a convenient smoking experience. In addition, aerosol generation requires less power than when generated with known vibration elements, for example those using heat.

As SAW-atomizer, commonly known SAW-sensor chips may be used. These typically comprise at least an interdigital (or interdigitated) transducer comprising (metal) electrodes arranged on a piezoelectric substrate, for example, printed onto the substrate. An AC voltage applied to the individual 'fingers' of the transducer electrodes cause the piezoelectric substrate to mechanically deform due to alternating regions of tensile and compressive strain in the piezoelectric substrate created between the fingers. As fingers on the same side of the transducer are at the same level of compression or tension, the space between them (known as pitch) corresponds to the wavelength of the mechanical wave.

The so generated waves typically have nanometer size amplitudes and propagate along the surface of the piezoelectric substrate at MHz frequencies.

Preferably, the at least one input transducer of the SAW-atomizer used in the smoking device according to the invention is an interdigital transducer comprising electrodes arranged on a piezoelectric substrate.

A transducer may comprise a reflector to support directionality of the generated surface acoustic waves into one direction. By this, power efficiency of a system may be increased.

A transducer may be configured to generate parallel waves, for example, by an array of straight electrodes arranged in parallel.

A transducer may be configured to have a focussing effect of the generated waves. For example, the transducer may be provided with electrodes having parallel but curved shapes such as to focus the generated wave to a small zone.

Preferably, a transducer comprises a reflector and has a focussing effect.

The control system of the smoking device is configured to operate the SAW-atomizer to generate surface acoustic waves at a predetermined frequency. The predetermined frequency may be about 20 MHz or higher, may for example be between about 20 MHz and about 100 MHz, or between about 20 MHz and about 80 MHz. This may provide a desired aerosol-output rate and a desired droplet size for a good user experience.

The control system may comprise electric circuitry connected to the SAW-atomizer and to a power source.

The electric circuitry may comprise a microprocessor, which may be a programmable microprocessor. The electric circuitry may comprise further electronic components. The electric circuitry may be configured to regulate a supply of power to the SAW-atomizer. Power may be supplied to the SAW-atomizer continuously following activation of the device or may be supplied intermittently, such as on a puff-by-puff basis.

The SAW-atomizer may be any suitable shape. The SAW-atomizer may be substantially circular or elliptical. The SAW-atomizer may be substantially triangular or square or any regular or irregular shape. Preferably, the SAW-atomizer is substantially flat. The SAW-atomizer may be curved. The SAW-atomizer may be dome shaped. The SAW-atomizer may be a substantially square plate. The SAW-atomizer may be a substantially circular or elliptical disc.

The SAW-atomizer may be reusable. The SAW-atomizer may be disposable. The SAW-atomizer may be a separate element or may be part of a cartridge as will be described below.

SAW-atomizers are generally small and light-weighted. In addition, SAW-atomizers, in particular having sizes suitable for use in electrically operated smoking devices, use less power than known vibration elements, for example those using heat for aerosol production. Yet further, SAW-atomizers generally have the ability to generate small droplet sized aerosol. These advantages of SAW-atomizers ameliorate the smoking device of the present invention and enable the provision of an efficient and economic smoking device.

The smoking device according to the invention may further comprise a heater arranged to heat liquid aerosol-forming substrate, preferably liquid aerosol-forming substrate in the atomization region. The heater may be arranged to heat at least a portion of the SAW-atomizer and by this the aerosol-forming substrate on the SAW-atomizer. Preferably, the heater is arranged to heat at least the atomization region of the SAW-atomizer and by this the aerosol-forming substrate in the atomization region.

The heater may heat the liquid aerosol-forming substrate and reduce the viscosity and the surface tension of the liquid. By heating the liquid preferably before but also during atomization, the heater may increase the rate of atomization. Heating the aerosol-forming substrate and reducing the viscosity of the liquid aerosol-forming substrate may increase the reliability of the device or the smoking system, respectively.

The heater may heat the liquid aerosol-forming substrate to a consistent, predetermined temperature for atomization. This may enable atomization of the aerosol-forming substrate at a consistent viscosity, and may enable generation of an aerosol by the device at a consistent rate of atomization. This may improve a user experience.

The viscosity of the liquid aerosol-forming substrate may have an effect on the rate of

atomization and on the droplet size of the aerosol generated by the device or system. Therefore, heating the liquid aerosol-forming substrate to a consistent, predetermined temperature before atomisation may facilitate generation of an aerosol having a consistent distribution of droplet sizes.

Heating the liquid aerosol-substrate to a temperature above ambient temperature before atomisation may also reduce the sensitivity of the system to fluctuations in ambient temperature and provide a user with a consistent aerosol at each use.

As used herein, the term 'droplet size' is used to mean the aerodynamic droplet size, which is the size of a spherical unit density droplet that settles with the same velocity as the droplet in question. Several measures are used in the art to describe aerosol droplet size. These include mass median diameter (MMD) and mass median aerodynamic diameter (MMAD). As used herein, the term 'mass median diameter (MMD)' is used to mean the diameter of a droplet such that half the mass of the aerosol is contained in small diameter droplets and half in large diameter droplets. As used herein, the term 'mass median aerodynamic diameter (MMAD)' is used to mean the diameter of a sphere of unit density that has the same aerodynamic properties as a droplet of median mass from the aerosol.

The mass median aerodynamic diameter (MMAD) of the droplets generated by the smoking device and system of the present invention may be between about 1 μm and about 10 μm, or the MMAD may be between about 1 μm and about 5 μm. The MMAD of the droplets may be equal to or less than 3 μm. The desired droplet size of the droplets generated by the smoking device of the present invention may be any MMAD described above. The desired droplet size (MMAD) may be equal to or less than 3 μm.

The control system of the smoking device may be configured to operate the heater to heat liquid aerosol-forming substrate to a predetermined temperature, preferably by heating at least a portion of the SAW-atomizer to a predetermined temperature. The predetermined temperature may be above ambient temperature. The predetermined temperature may be above room temperature. This may reduce the viscosity as well as the surface tension of the aerosol-forming substrate compared to the viscosity of the unheated aerosol-forming substrate. This may increase the rate of atomisation and may facilitate generation of an aerosol having desirable droplet sizes. This may reduce the sensitivity of the system to fluctuations in ambient temperature. The predetermined temperature may be below the vaporisation temperature or lower than the boiling point of the liquid aerosol-forming substrate. The predetermined temperature may be between 18 degree Celsius and 80 degree Celsius, or between 30 degree Celsius and 60 degree Celsius or between 35 degree Celsius and 45 degree Celsius. The predetermined temperature may be between 20 degree Celsius and 30 degree Celsius, 30 degree Celsius and 40 degree Celsius, 40 degree Celsius and 50 degree Celsius, 50 degree Celsius and 60 degree Celsius, 60 degree Celsius and

70 degree Celsius or 70 degree Celsius and 80 degree Celsius. Preferably, a predetermined temperature of a heated portion of the SAW-atomizer corresponds to the predetermined temperature of the liquid aerosol-forming substrate in the atomization region.

As used herein, the term 'ambient temperature' refers to the air temperature of the surrounding environment in which the aerosol-generating device or system is being used. Ambient temperature typically corresponds to a temperature between about 10 degree Celsius and 35 degree Celsius. As used herein, the term 'room temperature' refers to a standard ambient temperature and pressure, typically a temperature of about 25 degree Celsius and an absolute pressure of about 100 kPa (1 atm).

The control system configured to operate the heater may be integral or separate of the control system of the smoking device.

The control system may comprise electric circuitry connected to the heater and to an electrical power source. The electric circuitry may be configured to monitor the electrical resistance of the heater and to control the supply of power to the heater dependent on the electrical resistance of the heater. The electric circuitry may comprise a microprocessor, which may be a programmable microprocessor. The electric circuitry may comprise further electronic components. The electric circuitry may be configured to regulate a supply of power to the heater. Power may be supplied to the heater continuously following activation of the device or may be supplied intermittently, such as on a puff-by-puff basis. The power may be supplied to the heater in the form of pulses of electrical current.

The heater may be arranged on a surface of the SAW-atomizer, preferably next to the atomization region, or opposite the atomization region. For example, the heater may be arranged on a same surface of the SAW-atomizer as the atomization region. Such an arrangement allows a direct physical or close contact of the heater and the liquid aerosol-forming substrate to be heated, in particular close to the atomization region. A heater may, for example surround or partly surround the aerosol-forming substrate in the atomization region.

In arrangements, where the heater is arranged on a surface of the SAW-atomizer opposite the atomization region, a supply of aerosol-forming substrate to the atomization region is not altered by the presence of the heater. In addition, the heater may be arranged in a position of the atomization region but on an opposite side of a substrate of the SAW-atomizer. A size of the heater may correspond to the size of the SAW-atomizer. A size of the heater may be limited to the size of an atomization region. The size of a heater may at least correspond to the size of the atomization region. The position of the heater may be shifted in a direction of a supply element. This allows heating of the liquid before the liquid is in the atomization region. Preferably, heat of the heater is transferred through the substrate of the SAW-atomizer by heat conduction.

The positions of the heater as described may improve heat transfer between the heater

and the liquid aerosol-forming substrate on the SAW-atomizer.

The heater may be a separate heater attached to the SAW-atomizer or arranged next or near the SAW-atomizer.

The heater may be integral with the SAW-atomizer. This may reduce the number of component parts of the device and facilitate straightforward manufacture.

Preferably, the heater is in a heat conductive relationship with the SAW-atomizer.

The heater may also be arranged on or within the housing of the liquid storage portion. Liquid aerosol-forming substrate is then at an elevated temperature when being supplied from the liquid storage portion to the SAW-atomizer.

The heater may be any suitable heater capable of heating a liquid aerosol-forming substrate. The heater may be an electrically operated heater. The heater may be a resistive heater. The heater may comprise inductive heating means. The heater may be substantially flat to allow for straightforward manufacture. As used herein, the term 'substantially flat' means formed in a single plane and not wrapped around or otherwise confirmed to fit a curved or other non-planar shape. A flat heater may be easily handled during manufacture and provide for a robust construction.

The heater may comprise one or more electrically conductive tracks on an electrically insulating substrate. The electrically insulating substrate may comprise any suitable material, and may be a material that is able to tolerate high temperatures (in excess of 150 degree Celsius) and rapid temperature changes. An example of a suitable material is a polyimide film, such as Kapton®.

The control system configured to operate the heater or the SAW-atomizer or both may comprise an ambient temperature sensor, to detect the ambient temperature. The control system may comprise a temperature sensor on the SAW-atomizer, to detect the temperature of the liquid aerosol-forming substrate in the atomization region. One or more temperature sensors may be in communication with control electronics of the aerosol-generating device to enable the control electronics to maintain the temperature of the liquid aerosol-forming substrate at the predetermined temperature. The one or more temperature sensors may be a thermocouple or a resistive temperature sensor. The heater may be used to provide information relating to the temperature. Temperature dependent resistive properties of the heater may be known and used to determine the temperature of the at least one heater in a manner known to the skilled person.

In the smoking device according to the invention, a portion of the supply element may be arranged adjacent the atomization region of the SAW-atomizer while another portion of the supply element may be fluidly connectable to the liquid storage portion. The portion of the supply element arranged adjacent the atomization region may extend into the atomization region. In a ready to be used state of the smoking device, the supply element may allow the

transport of liquid aerosol-forming substrate from a liquid storage portion, for example from within a cartridge to the atomization region. Thereby, the other portion of the supply element may be directly connected to the liquid storage portion, for example inserted into or arranged adjacent a content of the liquid storage portion. However, the aerosol-forming substrate may also be transported out of the liquid storage portion, for example in a liquid passageway and be in fluid connection with the other portion of the supply element further downstream of a liquid transport from the storage portion to the SAW-atomizer. A separation of the liquid transport may enhance variability and optimization in liquid transport means from a liquid storage portion to the SAW-atomizer. In particular, a supply element for supply of liquid aerosol-forming substrate to the SAW-atomizer may be optimized for liquid supply to and distribution over the atomization region. On the other hand liquid transport out of the liquid storage portion may be optimized.

The supply element may be but is not limited to a capillary element, such as for example a wick or a strip of paper, a capillary or a piercing element for piercing a cartridge containing the liquid aerosol-forming substrate.

Preferably, the supply element is a capillary element having a capillary action for liquid aerosol-forming substrate. Preferably, the supply element in the form of a capillary element enables liquid aerosol-forming substrate to be supplied to the atomization region of the SAW-atomizer. The capillary element consists of or comprises material such that the liquid aerosol-forming substrate is transferred by a capillary effect. A capillary material is a material that actively conveys liquid from one end of the material to another. The capillary material is advantageously oriented in the device to convey liquid aerosol-forming substrate to the atomization region on the surface of the SAW-atomizer. The capillary material may have a fibrous structure or may have a spongy structure. The capillary material may comprise a bundle of capillaries, a plurality of fibres, a plurality of threads, or may comprise fine bore tubes. The capillary material may comprise a combination of fibres, threads and fine-bore tubes. The fibres, threads and fine-bore tubes may be generally aligned to convey liquid to the SAW-atomizer. The capillary material may comprise sponge-like material or may comprise foam-like material. The structure of the capillary material may form a plurality of small bores or tubes, through which the liquid can be transported by capillary action.

The capillary material may comprise any suitable material or combination of materials. Examples of suitable materials are a sponge or foam material, ceramic-, paper- or graphite-based materials in the form of fibres or sintered powders, foamed metal or plastics materials, sheet material, fibrous material, for example made of spun or extruded fibres, such as cellulose acetate, polyester, or bonded polyolefin, polyethylene, terylene or polypropylene fibres, nylon fibres or ceramic. The capillary material may be paper-based. The capillary material may have any suitable capillarity and porosity so as to be used with different liquid

physical properties.

The liquid aerosol-forming substrate has physical properties, including but not limited to viscosity, surface tension, density, thermal conductivity, and boiling point, which allow the liquid to be transported through the capillary material of the capillary element by capillary action. The capillary element may be configured to convey the liquid aerosol-forming substrate to the atomization region of the SAW atomizer. The capillary element be in the form of a sheet. Some capillary material, such as for example paper-based wick material, may additionally have the capability of filtering contaminants from the liquid, thus supporting atomization of the pure liquid aerosol-forming substrate.

The supply element may be a separate element or may be part of the SAW-atomizer. Preferably, the supply element is part of, for example, integral with the SAW-atomizer.

The supply element may be a wick element known in the art using capillary effects for transporting a liquid. The supply element may also use, for example, the Venturi effect, to transport liquid to the atomization region. The supply element may, for example, be microchannels integrated into a substrate of a SAW-atomizer, or any combination of the above mentioned supply elements.

The SAW-atomizer may comprise at least one piezoelectric transducer. The SAW-atomizer may comprise at least one interdigital transducer. The piezoelectric transducer may preferably comprise a monocrystalline material but may also comprise a polycrystalline material. The piezoelectric transducer may comprise quartz, a ceramic, barium titanate ($BaTiO_3$), lithium niobate ($LiNbO_3$). The ceramic may comprise lead zirconate titanate (PZT). The ceramic may include doping materials such as Ni, Bi, La, Nd or Nb ions. The piezoelectric transducer may be polarised. The piezoelectric transducer may be unpolarised. The piezoelectric transducer may comprise both polarised and unpolarised piezoelectric materials.

The SAW-atomizer may comprise one transducer for generating surface acoustic waves. The SAW-atomizer may comprise more than one transducer for generating surface acoustic waves. Transducers generating surface acoustic waves are called input transducers. Input transducers receive an electrical signal and generate surface acoustic waves according to the input signal. More than one input transducer may generate surface acoustic waves to interfere with each other, preferably positively interfere enhancing an energy input into the atomization region. An additional input transducer may be used to center the liquid in the atomization region or generally to center the liquid in a small zone.

The SAW-atomizer comprises more than one transducer. At least one of the more than one transducers is used for generating an electrical signal.

Transducers generating an electrical signal are called output transducers. An output transducer converts surface acoustic waves into an output signal. The surface acoustic waves received by the output transducer have been generated by the at least one input transducer

and have propagated along the atomization region of the SAW-atomizer to the output transducer. The output signal comprises information on physical processes in the atomization region, for example, on an amount of liquid present in the atomization region. Thus, the SAW-atomizer is used as a SAW-sensor gaining information on the atomization process. This information is used for controlling the atomization process. Sensor information is used in the control system controlling operation of the SAW-atomizer. Sensor information may also be used for example controlling a heater. A control of the atomization process may, for example, be achieved over an adjustment of power supplied to the SAW-atomizer.

The SAW-atomizer comprises at least one output transducer. The at least one output transducer is used for generating an electrical signal representative of physical information of the atomization region. The SAW-atomizer may comprise a further input transducer for generating further surface acoustic waves.

If two transducers are present, preferably, the two transducers are arranged opposite each other with the atomization region arranged in between the two transducers. A first one of the two transducers is an input transducer. A second one of the two transducers is an output transducer.

In the smoking device according to the invention, the liquid storage portion, the SAW-atomizer and the supply element may form parts of a cartridge. A cartridge including or excluding SAW-atomizer and supply element, may be premanufactured. The cartridge may be removable, replaceable, reusable or disposable. The cartridge may be refillable with liquid aerosol-forming substrate. With a refillable liquid storage portion or in particular with a replaceable cartridge, the smoking device becomes reusable. Preferably, the cartridge is not refillable and replaced after every use.

The device housing may comprise a cavity for receiving the cartridge.

The cartridge may be removably coupled to the aerosol-generating device. The cartridge may be removed from the aerosol-generating device when the aerosol-forming substrate has been consumed. As used herein, the term ‘removably coupled’ is used to mean that the cartridge and device can be coupled and uncoupled from one another without significantly damaging either the device or cartridge.

The cartridge may be manufactured at low cost, in a reliable and repeatable fashion. The cartridge may have a simple design. The cartridge may have a housing within which an aerosol-forming substrate is held.

The cartridge may comprise a liquid retention material holding aerosol-forming liquid. The cartridge may be a tank system filled with liquid.

The cartridge housing may be a rigid housing. As used herein ‘rigid housing’ means a housing that is self-supporting. The housing may comprise a material that is impermeable to liquid.

The cartridge may comprise a lid. The lid may be peelable before coupling the cartridge to the aerosol-generating device. The lid may be piercable, for example by the supply element.

A cartridge comprising a supply element and an SAW-atomizer allows for an entire 'fresh' atomization process any time a cartridge is replaced. Deposits or residues in the supply element or on the SAW-atomizer may be removed upon replacing a cartridge. The SAW-atomizer including supply element may also be reusable and preferably fixedly mounted elements of the smoking device. By this, waste and material cost may be reduced.

According to another aspect of the invention, there is provided a method for generating an aerosol in a smoking system. The method comprises providing a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer and at least a second output transducer. The method further comprises the step of providing a liquid aerosol-forming substrate to the atomization region of the SAW-atomizer and operating the SAW-atomizer, thereby generating surface acoustic waves with the at least one input transducer, the surface acoustic waves propagating along a surface of the SAW-atomizer into the atomization region and into the liquid aerosol-forming substrate in the atomization region, thereby atomizing the liquid aerosol-forming substrate and generating the aerosol. The method further comprises the steps of converting, using the at least one output transducer, the surface acoustic waves into an electrical signal representative of physical information of the atomization region, outputting the electrical signal with the at least one output transducer; and using the electrical signal for controlling operation of the SAW-atomizer The method may be performed using a smoking device, a smoking system and a cartridge in accordance with other aspects of the invention.

The method may have all the advantages described in relation to the other aspect of the invention. Features of the SAW-atomizer, such as for example operation modes, of the supply element, such as for example its arrangement and construction, of the heater, such as for example predetermined temperatures may be the same as those described in relation to other aspects of the present invention.

The method may comprise the step of fluidly connecting a liquid storage portion, for example a cartridge, comprising the liquid aerosol-forming substrate with the atomization region of the SAW-atomizer.

The method may comprise the step of providing a radio frequency signal to the at least one transducer.

The method may further comprise the step of supplying an amount of liquid aerosol-forming substrate to the SAW-atomizer, the amount of liquid corresponding to one puff.

The method may comprise the step of heating the liquid aerosol-forming substrate in the atomization region to a temperature above room temperature, preferably before atomization. Heating may be performed such that the liquid to be atomized has a temperature above 50

degree Celsius, for example a temperature between 50 and 80 degree Celsius.

The method according to the invention comprises the step of providing the SAW-atomizer with at least one output transducer.

The method comprises the steps of outputting an electrical signal with the at least one output transducer. The output signal is representative of a physical process in the atomization region. Said output signal is used for controlling operation of the SAW-atomizer. For example, the output signal may be used as input signal into a control system for controlling the SAW-atomizer or a heater.

The step of providing a surface acoustic wave atomizer may comprise providing a plurality of input transducers and the step of operating the SAW-atomizer may be carried out by generating surface acoustic waves with the plurality of input transducers, the surface acoustic waves propagating along the surface of the SAW-atomizer into the atomization region and into the liquid aerosol-forming substrate in the atomization region.

According to another aspect of the invention there is provided an aerosol-generating smoking system comprising a smoking device as described herein. The system also comprises a liquid aerosol-forming substrate. A supply element is in fluid connection with the liquid aerosol-forming substrate comprised in a housing of a liquid storage portion of the smoking device and with an atomization region on a surface acoustic wave atomizer (SAW-atomizer).

The liquid aerosol-forming substrate comprises at least one aerosol former and a liquid additive. The aerosol-former may, for example, be propylenglycol or glycerol.

The liquid aerosol-forming substrate may comprise water.

The liquid additive may be any one or a combination of a liquid flavour or liquid stimulating substance. Liquid flavour may for example comprise tobacco flavour, tobacco extract, fruit flavour or coffee flavour. The liquid additive may, for example, be a sweet liquid such as for example vanilla, caramel and cocoa, a herbal liquid, a spicy liquid, or a stimulating liquid containing, for example, caffeine, taurine, nicotine or other stimulating agents known for use in the food industry.

According to yet another aspect of the invention there is provided a cartridge for smoking devices for aerosol-generation. The cartridge comprises a liquid storage portion comprising a housing for holding liquid aerosol-forming substrate. The cartridge further comprises a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer for generating surface acoustic waves to propagate along a surface of the SAW-atomizer including the atomization region, and at least one output transducer for converting surface acoustic waves into an electrical signal representative of physical information of the atomization region. A supply element is provided and arranged to supply liquid aerosol-forming substrate from the housing of the liquid storage portion to the

atomization region on the SAW-atomizer.

The liquid storage portion, the SAW-atomizer, the supply element or a heater, may comprise any features or may be arranged in any configuration as described above in relation to the liquid storage portion, the SAW-atomizer, the supply element and heater of the aerosol-generating device as described herein. Advantages and features of the cartridge have been described relating to the smoking device and will not be repeated.

The invention will be further described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1	schematically illustrates an aerosol-generating device with a pierceable cartridge and a SAW-atomizer comprising a focussing transducer;
Fig. 2	schematically illustrates an aerosol-generating device with a SAW-atomizer comprising two focussing transducers;
Fig. 3	schematically illustrates an aerosol-generating device with a pierceable cartridge and a pointed SAW-atomizer comprising a focussing transducer;
Fig. 4	shows a SAW-atomizer with straight transducer;
Fig. 5	shows the SAW-atomizer of Fig. 4 with reflector;
Fig. 6	shows a SAW-atomizer comprising a straight transducer with different reflector and additional heating element;
Fig. 7	shows a SAW-atomizer with focussing transducer;
Figs. 8,9	show a top view and a cross section (along midline A-A) of a SAW-atomizer with focussing transducer, heating element and capillary element, in which the output transducer is not shown;
Figs. 10,11	show cross sections along midlines of further embodiments of SAW-atomizers with heating elements, in which the output transducer is not shown;
Figs. 12,13	shows a top view of and a cross section (along midline B-B) through a SAW-atomizer with two focussing transducers, in accordance with the present invention;
Figs. 14,15	shows a top view of and a cross section (along midline C-C) through a SAW-atomizer with supply element comprising microchannels, in which the output transducer is not shown;
Figs. 16,17	shows a top view of and a cross section (along midline D-D) through a SAW-atomizer with countersunk supply element, in which the output transducer is not shown;
Fig. 18	shows surface treatment of a SAW-atomizer, in which the output transducer is not shown.

Fig. 1 shows an electronic aerosol-generating device comprising a housing 10 and a mouthpiece 11. The housing comprises a cartridge 16 containing an aerosol-forming liquid, a surface acoustic wave-atomizer (SAW-atomizer) chip 15, electronics 14 for operating and controlling the SAW-atomizer, and a battery 13 providing power to the electronics 14 and the SAW-atomizer 15. The SAW-atomizer chip 15 is a rectangular chip comprising a focussing interdigital transducer 20 including reflector, which will be described in more detail below.

The cylindrically shaped cartridge 16 is closed at its distal end facing the SAW-atomizer chip with a sealing element, for example a pierceable or perforable foil 160. The sealing element is pierced by a supply element in the form of a pointed capillary element 30, for example a needle or a paper strip. The other, distal end of the capillary element 30 reaches to the focussing zone of the transducer 20 on the chip, the focussing zone corresponding to the atomization region 40 or vaporization region on the chip 15.

Fig. 2 shows another embodiment of an electronic aerosol-generating device, wherein the same reference numbers are used for the same or similar elements. In Fig. 2, the SAW-atomizer 15 comprises two focussing interdigital transducers 20 arranged opposite each other. The atomization region 40 lies in between the two transducers 20.

Both transducers may be operated to generate surface acoustic waves. By this, atomization in the atomization region 40 may be enhanced or less power may be required for achieving a same vaporization rate. Alternatively, one of the two transducers may be operated to provide a signal representative of the effects or condition in the atomization region, for example a vaporization rate or presence or absence of liquid. Said signal may be used in the electronics 14 to control and possibly adapt the atomization process.

In the embodiment of Fig. 2, the distal end of the cartridge 16 is closed by a layer of porous material 161. The porous material is in contact with a wick 31, for example a strip or strand of fibers or paper strip, the wick 31 extending from the porous material 161 to the atomization region 40 on the chip 15. Due to the arrangement of the two transducers 20 having a wave propagation direction substantially perpendicular to the longitudinal axis of the device, the wick 31 lies in between the two transducers.

Fig. 3 shows yet another embodiment of an electronic aerosol-generating device, similar to the one shown in Fig. 1, wherein the same reference numbers are used for the same or

similar elements. In Fig. 3, the SAW-atomizer chip 15 comprises a pointed tip portion 150 supporting a piercing of a pierceable membrane 160 of the cartridge. A capillary 32 is arranged to extend between the inside of the cartridge 16 and the atomization region 40 of the chip 15. The capillary 32 may, for example, be a microchannel.

An optional heater may be arranged on each side of the capillary, on top of the capillary or on the back side of the chip.

Figs. 4 to 17 show different embodiments of SAW-atomizer chips 15 and examples of arrangement and embodiments of transducers, capillary elements and heating elements.

In **Fig. 4** one interdigital transducer 21 is arranged on a lateral surface portion of a piezoelectric substrate. The transducer 21 comprises a series of straight interlacing electrodes 210 arranged in parallel (straight transducer). The atomization region 40 is indicated by a dotted line and is arranged near the transducer but on an opposite lateral surface portion of the piezoelectric substrate. In **Fig. 5** the same transducer 21 is provided with reflector electrodes 215. The straight reflector electrodes 215 are arranged parallel to the electrodes 210 of the transducer 21 and adjacent the side of the transducer opposite the side facing the atomization region 40. The reflector electrodes may reflect surface acoustic waves back into the intended propagation direction (to the right side in the drawing). The transducer 21 may for example have 20 electrode pairs and 32 reflector electrodes 215 arranged on a $LiNbO_3$ substrate. The electrode material may be gold.

The straight transducer of **Fig. 6** comprises reflector electrodes 216 arranged in between the transducer electrodes 210. A heating element, for example a resistive heater 50 in the form of a printed circuit path, is arranged on the substrate opposite the atomization region 40.

Fig. 7 is an example of a focussing interdigital transducer 20 having curved and tapering electrodes 211 focussing the generated waves onto a small focussing zone 200 on the surface of the substrate. In between the transducer electrodes 211, curved reflector electrodes 214 are arranged parallel to the transducer electrodes.

Fig. 8 shows the SAW-chip 15 of Fig. 7 with integrated heater 50 on the surface of the chip and a capillary element 31 in the form of a strip, for example a wick or capillary, arranged over the heater 50 substantially along the direction of the propagation direction of the waves generated by the transducer 21.

Fig. 9 is a cross section of the chip of Fig. 8. The transducer 20 and the heater 50 are arranged on the same surface, the top surface, of the piezoelectric substrate 151, for example a lithium niobate substrate. The wick 31 is partially arranged over the heater in close contact with same to support heating of liquid transported in the wick 31 from a cartridge (not shown) to the atomization region arranged between transducer 20 and heater 50.

Fig. 10 and **Fig. 11** show cross sections of further embodiments of SAW chips 15. In

Fig. 10 the heater 50 is arranged on an opposite side, the back side, of the substrate 151. The heater is positioned to 'extend' into the atomization region and 'overlap' with the wick 31, however with the substrate 151 in between. In order to reduce a way heat has to pass through the substrate to arrive at the liquid in the wick 31 or in the atomization region, the thickness of the piezoelectric substrate may be reduced. In Fig. 11, the transducer 20 and wick 31 is arranged on the surface of a piezoelectric layer 152, for example $LiNbO_3$, ZnO, AlN or other piezoelectric materials suitable for layers for SAW-atomizer applications. The heater 50 is arranged on the back side of the layer 152 at a same position as described and shown in Fig. 10.

The layer 152 is arranged on a support 153, for example a substrate made of glass, ceramic, silicon or metal. For manufacturing reasons, the heater may be applied to the substrate 153, which substrate is then provided with the piezoelectric layer 152.

While the heater has been shown to be arranged on the chip, a heater may also be arranged, for example, along a capillary material or channel between the chip and a cartridge comprising aerosol-forming liquid.

In **Fig. 12** and **Fig. 13** two focussing transducers 20 provided with reflector electrodes are arranged opposite each other on a piezoelectric substrate 151. The two transducers 20 have a common focussing zone 200 in between the transducers. In the focussing zone 200, the substrate 151 is provided with a through hole 155 through which aerosol-forming liquid may be supplied to the top surface of the substrate 151. A capillary element 33 is arranged below the substrate 151 for liquid supply to the bottom of the through hole 155. Optionally, the through hole 155 may be filled with capillary material. In this embodiment, the atomization area 41 is concentrated on the edges of the through hole 155 at the surface of the substrate 151. The sharp edges support the formation of a very thin aerosol-forming liquid layer, which facilitates its vaporization.

In **Fig. 14** and **Fig. 15** aerosol-forming liquid is supplied to the chip via a capillary element in the form of a sheet of wick material 34. The sheet 34 extends onto the surface of the substrate 151 and partially overlies a series of parallel microchannels 35 provided in the substrate surface. The microchannels extend into the atomization region of the straight transducer 21 also arranged on the substrate surface. However, the atomization area 41 is concentrated onto the edges of the microchannels.

A similar result, where an atomization region 41 is concentrated on a substrate edge 156 may also be achieve by a countersunk capillary element 36 as shown in **Fig. 16** and **Fig. 17**. A portion of the substrate surface has been removed, for example by etching. Onto this lower level surface portion, a capillary element, such as for example a strip of paper, is arranged flush with the edge 156 of the lower portion to enable liquid to be transported to the edge 156.

Also surface treatment of the substrate 151 may support the formation of thin aerosol-forming liquid layers. Surface treatment may also support a localization of such a layer. For example, and as shown in **Fig. 18**, an atomization region 40 (indicated by dotes lines) may be treated in order to form a hydrophilic area, while regions outside an indented atomization region may be hydrophobic areas 158.

Exemplary power ranges to operate an SAW-chip comprising one or two transducers in the aerosol-generating device according to the invention are 5 Watt to 15 Watt, preferably less than 20 Watt. Typical transducer electrode distances are in a range of about 100 micrometer (straight transducers), while reflector distances may be in a range of about 50 micrometer.

Sizes of rectangular SAW-chips comprising two transducers are about 50mm times 20mm to 55mm times 25mm.

Exemplary aerosol-forming liquid compositions were 40 percent to 80 percent propylenglycol, 20 percent water and 0 percent to 40 percent glycerol. The aerosol-generating liquid was heated to about 65 degree Celsius. An amount of about 5 microliter of such a liquid was atomized or vaporized in less than 20 seconds, achieving a vaporization rate of about 0.2 to 0.3 microliter per second or higher.

CLAIMS

1. Smoking device for aerosol-generation of a liquid aerosol-forming substrate, the smoking device comprising:

- a device housing comprising a liquid storage portion comprising a housing for holding liquid aerosol-forming substrate;

- a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer for generating surface acoustic waves to propagate along a surface of the SAW-atomizer including the atomization region, and at least one output transducer for converting surface acoustic waves into an electrical signal representative of physical information of the atomization region;

- a supply element arranged to supply liquid aerosol-forming substrate from the liquid storage portion to the atomization region on the SAW-atomizer; and

- a control system configured to operate the SAW-atomizer for atomizing the liquid aerosol-forming substrate in the atomization region to generate an aerosol, wherein the control system is configured to control operation of the SAW-atomizer according to the electrical signal.

2. Smoking device according to claim 1, wherein at least one of the input and output transducers is an interdigital transducer comprising electrodes arranged on a piezoelectric substrate.

3. Smoking device according to any one of the preceding claims, further comprising a heater arranged to heat liquid aerosol-forming substrate.

4. Smoking device according to claim 3, wherein the control system is configured to operate the heater to heat liquid aerosol-forming substrate to a predetermined temperature.

5. Smoking device according to any one of claims 3 or 4, wherein the heater is arranged on a surface of the SAW-atomizer next to the atomization region or on a surface of the SAW-atomizer opposite the atomization region.

6. Smoking device according to any one of the preceding claims, wherein a portion of the supply element is arranged adjacent the atomization region of the SAW-atomizer and another portion of the supply element is fluidly connectable to the liquid storage portion.

7. Smoking device according to any one of the preceding claims, wherein the supply element is a capillary element having a capillary action for liquid aerosol-forming substrate to be

supplied to the atomization region of the SAW-atomizer.

8. Smoking device according to any one of the preceding claims, wherein the at least one input transducer comprises a plurality of input transducers for generating surface acoustic waves.

9. Smoking device according to any one of the preceding claims, wherein the liquid storage portion, the SAW-atomizer and the supply element form parts of a cartridge, and wherein the device housing comprises a cavity for receiving the cartridge.

10. Method for generating an aerosol in a smoking system, the method comprising:

- providing a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer and at least one output transducer;

- providing a liquid aerosol-forming substrate to the atomization region of the SAW-atomizer;

- operating the SAW-atomizer, thereby generating surface acoustic waves with the at least one input transducer, the surface acoustic waves propagating along a surface of the SAW-atomizer into the atomization region and into the liquid aerosol-forming substrate in the atomization region, thereby atomizing the liquid aerosol-forming substrate and generating the aerosol,

- converting the surface acoustic waves into an electrical signal representative of physical information of the atomization region, using the at least one output transducer,

- outputting the electrical signal with the at least one output transducer; and

- using the electrical signal for controlling operation of the SAW-atomizer.

11. Method according to claim 10, further comprising the step of heating the liquid aerosol-forming substrate in the atomization region to a temperature above room temperature.

12. Method according to any one of claims 10 to 11, wherein the step of providing a surface acoustic wave atomizer comprises providing a plurality of input transducers, and wherein the step of operating the SAW-atomizer is carried out by generating surface acoustic waves with the plurality of input transducers, the surface acoustic waves propagating along the surface of the SAW-atomizer into the atomization region and into the liquid aerosol-forming substrate in the atomization region.

13. Aerosol-generating smoking system comprising a smoking device according to any one

of claims 1 to 9, and a liquid aerosol-forming substrate, wherein a supply element is in fluid connection with the liquid aerosol-forming substrate comprised in a housing of a liquid storage portion of the smoking device and with an atomization region on a surface acoustic wave atomizer (SAW-atomizer).

14. Aerosol-generating system according to claim 13, wherein the liquid aerosol-forming substrate comprises at least one aerosol former and a liquid additive.

15. Cartridge for smoking devices for aerosol-generation, the cartridge comprising:

a liquid storage portion comprising a housing for holding liquid aerosol-forming substrate;

a surface acoustic wave atomizer (SAW-atomizer) comprising an atomization region, at least one input transducer for generating surface acoustic waves to propagate along a surface of the SAW-atomizer including the atomization region, and at least one output transducer for converting surface acoustic waves into an electrical signal representative of physical information of the atomization region;

a supply element arranged to supply liquid aerosol-forming substrate from the housing of the liquid storage portion to the atomization region on the SAW-atomizer.